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The Optoelectronic Materials Center is a collaborative program involving the University of New Mexico, Stanford University, and the California Institute of Technology. Sandia National Laboratories and MIT Lincoln Laboratory are also involved in this program under separate contract vehicles. This program emphasizes three main area:

diode-based visible sources
two-dimensional optical interconnects, and
high-speed optoelectronics.

Progress on individual tasks is very briefly discussed below. Several of the tasks will impact more than one of the above areas. For simplicity, the tasks are arranged by institution in an order roughly determined by the above areas.

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DARPA Quarterly Report

Period ending December 1991

UNIVERSITY OF NEW MEXICO
CENTER FOR HIGH TECHNOLOGY MATERIALS

Visible Diode Lasers

Personnel

Professor Christian Schaus left UNM this quarter to join a start-up company in Oregon. Professor Steve Hersee has joined CHTM from GE, and is now responsible for the MOCVD Crystal Growth Facility. Dr. Hersee is a successful technical contributor in three countries in the field of III-V semiconductor materials and devices. He has led many successful programs including: first growth of quantum well lasers by MOCVD (1982), world record quantum-well laser performance at Thomson CSF (1982), US patent award for metalorganic molecular beam epitaxy (MOMBE) hardware, and demonstration of state-of-the-art MOMBE AlGaAs (1990).

MOCVD Materials Growth

Facilities and Equipment

Extension to Crystal Growth Facility

Construction plans for the extension to the crystal growth facility were completed, and ground-breaking began during this quarter. The design emulates major features of the existing building, and we estimate completion in July 1992. The plan is designed for minimum interruption of work in the existing building and will allow us to continue MOCVD epitaxial growth during the construction period.

New MOCVD Reactor

Specifications for the new MOCVD reactor were completed, and the bid process is underway. We have received six proposals in response to this bid from the following equipment manufacturers:

Aixtron (Germany)
Caleb (USA)
CVT (UK)
Epiquip (Sweden)
Thomas Swann Ltd. (UK)
MR Semicon (UK)

These proposals are being evaluated in detail. None of these manufacturers can guarantee our required uniformity specification (0.5%) in an off-the-shelf reactor design. We therefore expect that we will need to work with the vendor to fine tune the reactor and extend state-of-the-art technology to this new level of uniformity. Two manufacturers, Emcore (USA) and Spire (USA), declined to bid on this project. (S. Hersee)

Vertical Cavity Surface Emitting Lasers (VCSELs)

In this quarter, we have greatly extended the versatility of our VCSEL-based optical switching technology by demonstrating that very high optical gain and optical memory can be achieved with an optical switch based on the integration of a VCSEL with a latching heterojunction photothyristor (a PNPN device). This integrated PNPN/VCSEL switch has an epitaxial structure that is similar to the monolithic integrated HPT/VCSEL switch previously reported. The two types of switches with different functional characteristics thus share a common epilayer structure, and are readily integrable on a common substrate. Because of the strong regenerative positive feedback in a photothyristor, the PNPN/VCSEL switch can be triggered at an extremely low optical threshold (15 nW), while outputting an optical power of over 1.2 mW (a lower cw of 0.4 mW is obtained due to heating effects). The optical gain can thus be as high as 10^4-10^5, with an optical contrast of 30 dB. Latching characteristics were demonstrated under pulsed conditions, and the switched VCSEL remains on without any optical bias, as long as the bias voltage is sufficient to keep it above lasing threshold. The switching threshold is tunable via the bias voltage. A low switching energy of 6 pJ has been demonstrated.

During the past few quarters, we have devoted a fair amount of effort to the evaluation, qualification, and acquisition of a suitable plasma processing system for etching compound semiconductor heterostructures with an arbitrary profile, which may be selective or non-selective with respect to material or crystallographic differences. The requirements for some of our device applications are particularly stringent. For example, the etching of very high aspect ratio (vertical) profiles without any material or crystallographic preference is required for the fabrication of VCSELs, whereas lower aspect ratio sidewalls are required for interconnections in the VCSEL-based switches, in which the etch depth must be precisely controllable to a tolerance of 30-50 nm. We have evaluated various types of plasma-enhanced or microwave-enhanced, and chemically-assisted etching systems and processes and have selected the appropriate machine and etching process. (Julian Cheng)

High-power Picosecond Pulse Generation Using Diode Lasers for Widespread Optical Clock Distribution and Time-division Multiplexing.

High Power and Visible Semiconductor Lasers

Work has continued on optical pumping of GaAlAs/GaAs and InGaAs/GaAs vertical cavity lasers with periodic gain (RPG-VCSELs) to investigate the wavelength

dependence of optical pumping performance in the 800-950 nm region. Experiments performed using pulsed and CW tunable titanium-sapphire lasers indicate the existence of a very efficient (albeit narrow) pumping band corresponding to a cavity mode just above the lasing photon energy, This is just as efficient as pumping the spacers between quantum wells at ~750 nm. A strained InGaAs/GaAs RPG-VCSEL, which lased at 900 nm, was pumped at 890 nm in this way. This very small quantum defect bodes well for possible high power diode laser or laser array pumping.

The anamorphic stable/unstable external cavity concept described in previous reports has been extended to develop monolithic unstable resonators on high-power laser chips. In the first approach, a series of diverging lenslets was etched and buried by regrowth in a GaAs layer just above the asymmetric GRIN-SCH SQW active layer of a unique laser structure developed at CHTM. The results were very promising. Nearly diffraction limited output powers of almost 500 mW were obtained from 100 and 170 mm stripe devices with round trip mode magnification factors of up to 6.4.

High speed optoelectronics

Further experiments were conducted to examine the stability of an actively mode-locked Hitachi HLP-1400 GaAs/AlGaAs double heterostructure laser with respect to modulation detuning and amplitude. The system is sensitive to detunings of ~100 kHz for stable pulses; there is a strong tendency toward multiple pulses, probably as a result of imperfect anti-reflection coating on the internal facet of the laser chip. Pulses remained detector-limited at ~100 ps; a new photodiode detector system is being designed, and a streak camera has been loaned to UNM by our OMC colleagues at Sandia National Laboratories.

The first attempt at fabricating laser mode switches, bistable optical devices, and beam position scanners, which were designed based on the closely coupled twin-stripe semiconductor laser amplifier, did not yield any useful devices.

Parallel optoelectronics

An overall system design for a time-division multiplexed optical fiber communication system has been constructed, based on 2-D arrays of surface-normal optoelectronic devices such as RPG-VCSELs, spatial light modulators, and optical threshold detectors based on nonlinear etalons. This work, which is supported by NSF, is closely related to the DARPA OMC because of its reliance on parallel optoelectronic signal generation/processing devices.

During the next six month period, we plan to:

- Optimize high-power pulsed operation of RPG-VCSELs by reducing lasing threshold and raising pump damage threshold in RPG-VCSEL samples.

- Investigate transverse mode behavior of high power optically pumped RPG-VCSELs and continue to consider how to develop high power diode laser or laser array pumping.

- Conduct further studies of the monolithic unstable resonators on high-power laser chips.

- Assess feasibility of self-mode-locking of semiconductor lasers for ~1 ps transform-limited pulses at gigahertz repetition rates.

- Perform a second fabrication cycle for twin-stripe laser amplifier switches and bistable elements.

- Fabricate and evaluate MQW nonlinear etalons and investigate thresholding behavior for time division demultiplexing of optical signals. (McInerney)

Surface Normal Second Harmonic Generation in Waveguides.

During this quarter, we have investigated planar GaAs-based waveguide structures. We found that the multitransverse mode of our wide ridge waveguides results in wide far-field SH patterns, as the sightly different propagation constants for each mode give slightly different angular displacements. Photographs show that this far-field band is composed of several bright bands representing the transverse modes in the waveguides. While this certainly offers an opportunity to investigate the modal behavior of one-dimensional guides, our first experiments were to investigate the counterpropagating SHG in planar structures.

We observed much narrower far-field patterns owing to the fact that only a single TE mode with no lateral wave vector can result in counterpropagating overlap. Modes coupled into the waveguide with a transverse vector never overlap upon reflection from the back facet. While the power was considerably lower, the near-field and far-field showed a much cleaner pattern.

We also attempted to study the generation of a blue second harmonic in several of our waveguide structures. We were unable to couple in a 790-nm fundamental wavelength in some cases, and our study shows that absorption losses will be very high in the GaAs waveguide structures that work in the green.

We began development of the computer code necessary to study the efficiency properties of these structures. Our code consists of two parts: a fundamental wavelength portion aimed at calculating the fundamental profile in a given structure, and the SHG portion that accounts for generation, summation, and important loss mechanisms as the SH propagates to the surface.

Our computer model will be used to optimize the design of a multilayer waveguide consisting of alternating generation and phase shifting layers. We will consider accurately the $Al_{(x)}Ga_{(1-x)}As$ materials system where good index and absorption

coefficient data exist. Preliminary results suggest that the $\lambda_{2\omega}$ spacing might not be the most efficient. We will also study the use of high Al composition waveguides to optimize the production of 475 nm blue light using a 950 nm fundamental from our newly acquired titanium-sapphire laser.

No changes in personnel. (Malloy)

<u>Visualization of Complex 3D Integrated Circuits</u>

We are using electric field induced SHG in thin films of 28/0/100 PLZT to visualize electric fields. The key question that we are trying to answer is how fast does the PLZT react to the application of the electrical field. To answer that question, we constructed fast photoconductive transmission line switches. SHG is probed locally with ps IR pulses (1.06 μm), as the E-field propagates along the transmission line.

Several coplanar stripline circuits were deposited on glass, silicon on sapphire, and semi-insulating GaAs. The circuit consists of a narrow (20 μm) central electrode, sandwiched between two conductive surfaces. The spacing between electrodes is 20 μm. The central electrode and one of the conducting surfaces is at high potential (up to 30 V). A ps pulse at 530 nm is used to locally short the area between the high and ground electrodes. As the wave propagates along the transmission line, a field appears between the central electrode and the electrode originally at high potential. A glass plate with a PLZT thin film is pressed on top of the circuit. The propagating E-field is probed by observing the second harmonic generated by a delayed probe IR picosecond pulse.

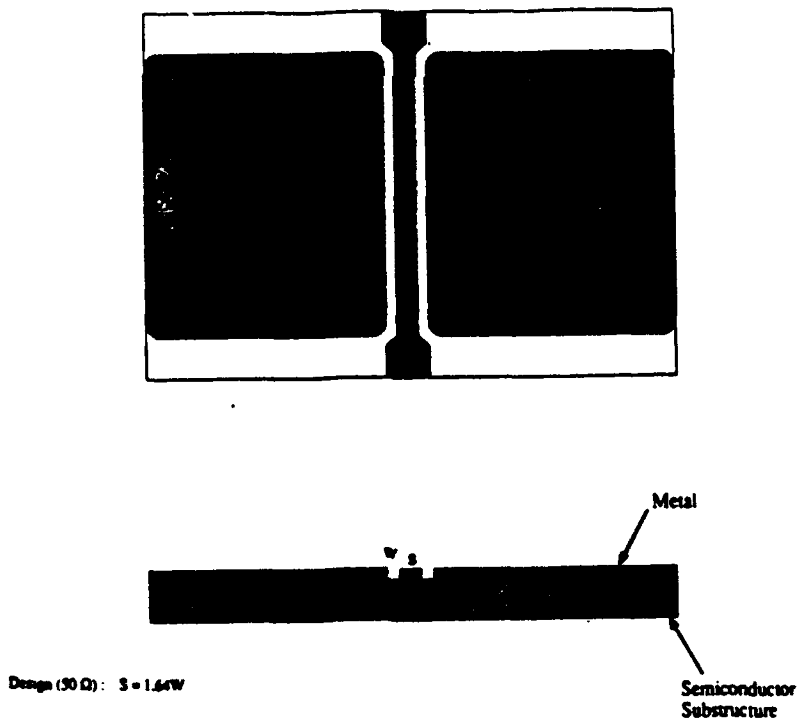

Figure 1. Sketch of Coplanar Stripline

The two beams (switching beam at 530 nm and probe beam at 1060 nm) are sent through a microscope onto the sample. The field induced SHG green light can be observed directly with the eyes. The problem of uniform contact between the PLZT film and the circuit has not been resolved satisfactorily. We are presently experimenting with films

of different thickness and substrates of varying optical quality. Attempts are also being made to deposit PLZT directly on the circuit. (Diels)

Basic Properties of Quantum Well Materials

Explore Semiconductor Structures for Novel Quantum Mechanical Effects, Including Shaped- and Coupled-Quantum Wells.

Having determined that the choice of effective-mass operator ordering can manifest itself in substantial shifts of optical transition energies in quantum wells, we have attempted to fit various experimental data available in the literature. Both intraband and interband transition energies have been examined. Comparison with experimental data leads to a Hamiltonian consistent with earlier microscopic calculations.

Next quarter we plan to consider the effect of operator ordering on exciton binding energies.

Thermal Properties of Electrically Pumped VCSELs

Design, Fabricate, and Characterize Electrically Pumped, AlGaAs and InGaAs-Based, Vertical-Cavity, Surface-Emitting Lasers with the Goal of Room Temperature, Continuous Wave Operation at an Output Power 1 mW or Greater.

Thermal-electrical analysis of etched-well VCSELs has been employed to optimize their design, with the maximum excess current over the cw threshold taken as the optimization criterion. A new thermal-electrical model of proton-implanted VCSELs has been developed.

In the next quarter we plan to develop a simple method to estimate thermal resistance of planar proton-implanted top-surface-emitting lasers. and analyze spreading resistance in proton-implanted VCSELs.

Demonstrate Electrical Modulation of Individual Surface-Emitting Lasers in a Two-Dimensional Array Format and Study the Feasibility of a Time-Multiplexed Matrix-Addressed Source Array.

Thermal crosstalk in large-size ("infinite") two-dimensional arrays of etched-well VCSELs has been analyzed. Severe thermal effects are predicted for closely packed arrays.

For the next quarter we plan to determine design guidelines for two-dimensional arrays of etched-well VCSELs with tolerable thermal cross-talk. (Osinski)

PLZT

We have used rutile prisms to couple light into PLZT thin films on SiO_2/Si with partial success. Film thickness and refractive index can be determined easily using the prism coupling technique. It was difficult to couple the light out of the film using a second prism, and this prohibits us from measuring attenuation loss in the film. All the prisms have scratches and defects on their surfaces and a requisition has been made to polish these prism surfaces.

Recently surface second harmonic generation has been detected on PLZT film by using a ND:YAG laser. The sample is 7/0/100, <100> oriented film. An output power versus input power will be measured soon to assure that the green light is the true SHG in the sample.

A measuring system is being set up for measuring the attentuation loss in the film, using a fiber detection system. Preliminary results show that attenuation is ≈50 dB/cm. Since scattering from channel ridge is severe, we are trying to improve the channel ridge by using a plasma etching technique currently being set up in the thin film laboratory. (Wu)

STANFORD UNIVERSITY

Report for period ending 9/91

Visible Light Sources:

In the previous quarter, in addition to the steady progress towards the goals outlined in the proposal, we have started a number of new and promising approaches to achieve visible light generation and modulation in semiconductors.

Development of II-VI Materials

Since our last report, we have commenced the growth and characterization of zinc selenide (ZnSe) on GaAs. Using the organometallic sources diisopropyl selenide and diethyl zinc, specular films have been grown at 350 and 400°C. The growth is surface reaction rate limited, showing a growth activation energy of approximately 0.4 to 0.7 eV. These materials were recently measured by photoluminescence. At low temperatures they luminesce strongly at the bandgap, indicating good material quality. There is also some emission at lower energies, in the orange part of the visible spectrum. Since the intensity of this peak varies inversely with sample thickness, it is believed that the orange emission is coming from the interface between the GaAs substrate and the ZnSe epilayer. The agreement of the blue peaks with specific exicitonic complexes is still to be determined. (Gibbons, Fejer)

High Speed Optoelectronic Measurements

Work on external cavity surface emitting lasers continued with the design, growth, and initial characterization of laser material to operate at 850 nm. We have also made considerable progress with the high speed detector measurements by demonstrating a high speed photodiode integrated with a nonlinear transmission line sampler. Using this monolithic approach, we achieved a 1.8 ps temporal impulse response corresponding to 200 GHz - 3dB bandwidth. This is the fastest photodiode to our knowledge. The photodiode was a 5X5 μm semitransparent GaAs Schottky diode. The overall quantum efficiency was 33%. (Bloom)

High Speed Modulators

We have recently found that indirect gap AlGaAs/AlAs quantum wells may be a good alternative for the generation and modulation of visible radiation. Examining quantum well samples with zone center bandgaps at 630 nm and 510 nm, we observed clear excitonic absorption and found that the exciton shifts with field, yielding absorption changes of a few thousand per centimeter. The measured absorption ratio (max

absorption/min absorption) was about 6 at 630 nm. Such quantum wells may allow the fabrication of efficient modulators operating in the visible spectrum. We also observed strong electroluminescence at 630 nm from the first sample. We found that the light intensity decayed at lower temperatures, implying that the carriers are thermally excited from the long-life, indirect states to the higher energy quantum well state. Since the radiative recombination rate is very fast from the direct gap quantum well state, the overall efficiency can be quite large. We plan to further asses the quality of such wells for modulators and displays.

As a simple demonstration of the utility of such material, we used the quantum well sample as a simple modulator. Even without a back mirror or a Fabry-Perot cavity we obtained a reflectivity modulation of 7%. Using this device in series with a HeNe laser, we could apply electronic feedback to cancel the intensity noise present in the laser. We lowered the low frequency intensity noise by about three orders of magnitude using this simple technique. (Harris)

Report for period ending 12/91

Development of II-VI Materials

Previous work on the FIB/MBE interface was rewarded this quarter by experimental results on the material quality. The ramifications of *in-situ* processing of MBE samples by focused ion beam bombardment were examined by measuring the 77° K photoluminescence intensity of regions irradiated by beams of various doses and energies. The effect was largely dose-invariant over several orders of magnitude, but exhibited strong dependence on incident ion energy. Low-energy (25 eV) irradiated regions exhibited the same PL signal as nonirradiated regions and control samples not subjected to MBE growth suspension for *in-situ* processing. Additional experiments will asses the material quality via DLTS measurement and PL intensity of quantum well structures similarly bombarded.

Work has continued in patterning the orientation of II-VI films on GaAs. We have optimized our *in-situ* prebake to obtain a clean surface suitable for further epitaxy without degrading the patterned layers that are already in place on the GaAs substrate. Diulte bromine in methanol (Br:MeOH =1:100) was found to be a suitable etch for CdTe. A preliminary test of orientation patterning was performed as follows: First, a <111> oriented CdTe layer was grown on bare GaAs. Part of the wafer was masked with black wax, and the CdTe was etched with Br:MeOH. The wafer was re-entered into the reactor, and the above preclean was performed. A 20 Å layer of ZnTe was grown, followed by a thick layer of CdTe. This resulted in <100> material where the wafer had been etched, and <111> where it had been masked. Further optimization of the processing is underway in order to fabricate the desired waveguide/quasi-phase matched structure. (Gibbons/Fejer)

Second Harmonic Generation in Periodically-Poled Materials

Our goal of increasing the efficiency of blue light generation in $LiNBO_3$ met with considerable success this quarter. We increased the amount of blue light generated in a quasi-phase matched waveguide to over 1mW with an input power of 200mW; this compares with 14.7 nW of blue light generated in the initial demonstration. Theoretical modeling and demonstration of proton exchanged (PE) $LiNbO_3$, waveguides, which are insensitive to first order variations in phase mismatch have been accomplished, and implementation in a quasi-phasematched device should increase interaction lengths. We have undertaken a detailed characterization of the modal properties of annealed proton

exchanged (APE) waveguides in both z- and x-cut $LiNbO_3$ and studies of the nonlinear susceptibility in PE and APE waveguides are ongoing. These experiments allow us to calculate the waveguide dimensions that optimize the overlap integral between the nonlinear polarization and the second harmonic field By increasing the conversion efficiency per unit length and the overall interaction length, we hope to generate mW levels of blue light with commercial diode lasers.

We have also explored $LiTaO_3$, which is over 30 times more resistant to photorefractive damage. Spatial modulation of the nonlinear susceptibility was accomplished using a periodic electric field. We achieved 13 mW of blue light with 41 mW of infrared input power. A number of significant publications have resulted from this quarter's progress. (Fejer)

<u>High Speed Optical Modulators and Measurements</u>

Our work with Fabry-Perot modulators has resulted in an experimental device that uses absorption changes to modulate the reflected phase. The device can currently switch the phase by 90 degrees at a constant reflectivity of 30%. We are currently designing an optimized device capable of 180degree phase reversal over a large wavelength range. Our measurements of phase modulation in normal intensity modulators has also shown very low chirp characteristics, suitable for dispersion limited optical interconnects. (Harris)

CALIFORNIA INSTITUTE OF TECHNOLOGY

<u>Dislocation Density Reduction and Island Suppression in Epitaxial Ge Growth on Si by Ion-Assisted Molecular Beam Epitaxy</u>

Currently there is considerable interest in misfit accommodation in hetero-epitaxy for integration of device-quality III-V and II-VI films with Si integrated circuit technology. Despite many advances, no process has yet demonstrated adequate control of misfit dislocations. Of particular interest is the control of misfit accommodation that results in either: (i) smooth, coherently strained layers; and (ii) reduction or elimination of defects from the *active* region, possibly at the expense of defect creation elsewhere in the film. Ion-assisted molecular-beam-epitaxy is one of a class of techniques that allows modification of the growth kinetics during heteroepitaxy, with the potential for novel means of misfit accommodation.

In the last quarter, we have demonstrated, using ion-assisted molecular beam epitaxy:

- Reduction of dislocation density in thick Ge growth on Si by a factor of four.

- Suppression of island formation during heteroepitaxy of thin films with large misfits

We have observed a reduction of the threading dislocation density in the Ge-films grown on Si in a two-step process with (i) 30-nm Ge-film grown at 300°C (growth-rate limited regime) with 200-eV low energy ion bombardment annealed at 550°C for 30 min. and (ii) 320-nm Ge-film grown at 550°C on top of the annealed buffer layer, compared with 350-nm Ge-film grown at 550°C. In typical two-step growth, the

buffer layers are annealed at temperatures higher than the final film growth temperature, while in this process, the maximum temperature used was the final growth temperature. The threading dislocation density is reduced by a factor of approximately 5 as compared with similarly-processed thermal-growth samples.

We have also investigated suppression of the Ge island formation on Si using low energy ion bombardment during growth. The films bombarded by the low energy ion beam (70-150 eV, with ion-to-atom flux ratio in the range of 0.01 to 0.2) grow in a layer-by-layer mode up to 3 nm, whereas islanding occurs for thermally grown films at a thickness of 1 nm. The driving force for islanding still exists, as films smooth, coherent films grown at 400°C exhibit island formation upon annealing at 600°C. This suggests that the film is coherently strained, and that low energy ion bombardment results in dynamic dissociation of incipient islands during the early stages of growth.

We plan to investigate dislocation density reduction by enhancing the threading dislocation mobility in graded epitaxial buffer layers. We will also investigate GaAs and ZnTe growth on the substrates with pure Ge and graded buffer layers. (Harry. A. Atwater)

Nanometer-Scale Selective Growth of GaAs and InGaAs by OMVPE and Application to Quantum Size Effect Semiconductor Lasers

Currently there is a great interest in the fabrication of structures that are two and three dimensional analogs of the conventional quantum well. Several potential applications of arrays of such structures have been proposed, including diode laser active layers and new nonlinear apticall materials. Key problems involved in successfully applying these structures in devices are interface quality and abruptness, structural uniformity, and, for application to lasers, ability to efficiently pump the structures without leakage effects dominating. Selective growth is a potential candidate for fabricating highly uniform nanostructures and for providing extremely good built-in current blocking capability, which could be expoited in ultra-low threshold conventional quantum-well laser diodes.

The OMVPE reactor for our quantum-structure work with DEGaCl selective epitaxy, located at the NASA Jet Propulsion Laboratory, has been modified extensively to meet the rigorous requirements of quaternary compound InGaAsP growth and to improve the current AlGaAs growth characteristics.

A self-purging high-purity nitrogen glovebox with gas interlock chambers has been installed to prevent any contamination of growth chamber with oxygen or water vapors. The layouts for the glovebox and modifications have been designed. Most of the necessary components for the modifications have been purchased. Other aspects of the current reactor design are being reviewed for the feasibility of further modification. (Vahala)

Ultra-low Threshold Semiconductor Lasers

To further reduce laser thresholds, high reflectivity coatings were applied to the laser facets. Threshold current drop from 1.5 mA for the uncoated double quantum well laser to a world record low 0.35 mA after increasing both facet reflectivities to 0.95. We observe a shift in lasing wavelength from 975 nm to 955 nm after the coating process,

which is due to the lowered gain requirement. Optical output power vs. DC input current for our best device with and without mirror coatings is presented in Figure 2. (Yariv)

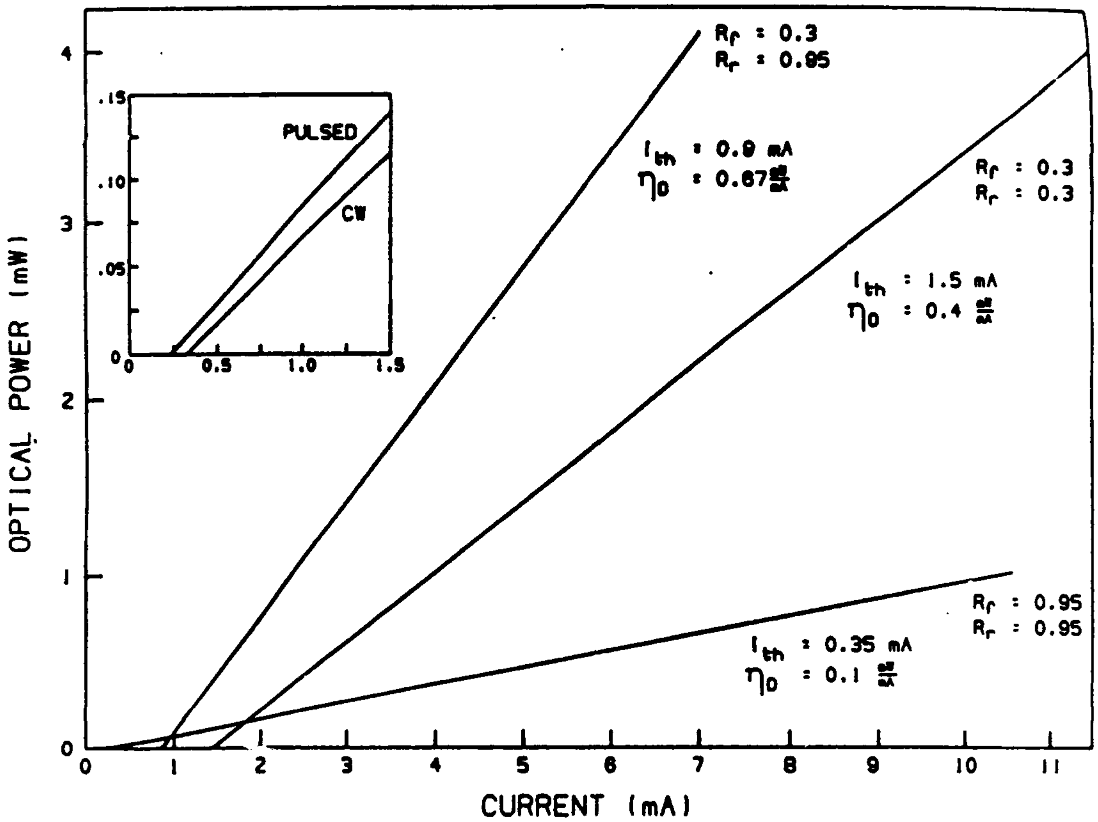

Figure 2. DQW BH Laser With Various Facet Reflectivities

Massively Parallel Optical Networks

We have fabricated a number of different optoelectronic nonlinear thresholding circuits in GaAs for neural network applications. In looking at the choices and tradeoffs for such a circuit, we define a figure of merit to judge the performance of various optoelectronic neuron implementations where the parameter we wish to optimize is the number of connection updates/sec-cm^2. For incoherent optical neural networks, this figure of merit is simply

$$\frac{NG}{\tau}$$

where N is the number of neurons per cm^2. G is the optical gain, and τ is the switching time of the circuit.

One of the first issues with which to be concerned is whether one should use optical modulators or sources such as LEDs or lasers. Modulators have the advantage that electrical power dissipation is not a function of the optical gain. On the other hand, modulators require high bias voltages and require an external light source. While lasers are more efficient and faster than LEDs, lasers have a threshold current to overcome,

which limits the density of neurons due to power dissipation problems. Figure 3 shows the density of neurons as a function of the switching time. The linear regions for the LED and the modulator represent the region where the ciruit is limited by electrical power dissipation. As the switching time increases, we can afford to operate at a lower power, thus the density increases. The upper bounds are due to geometrical limits, for the laser the curve is nonlinear due to the threshold current.

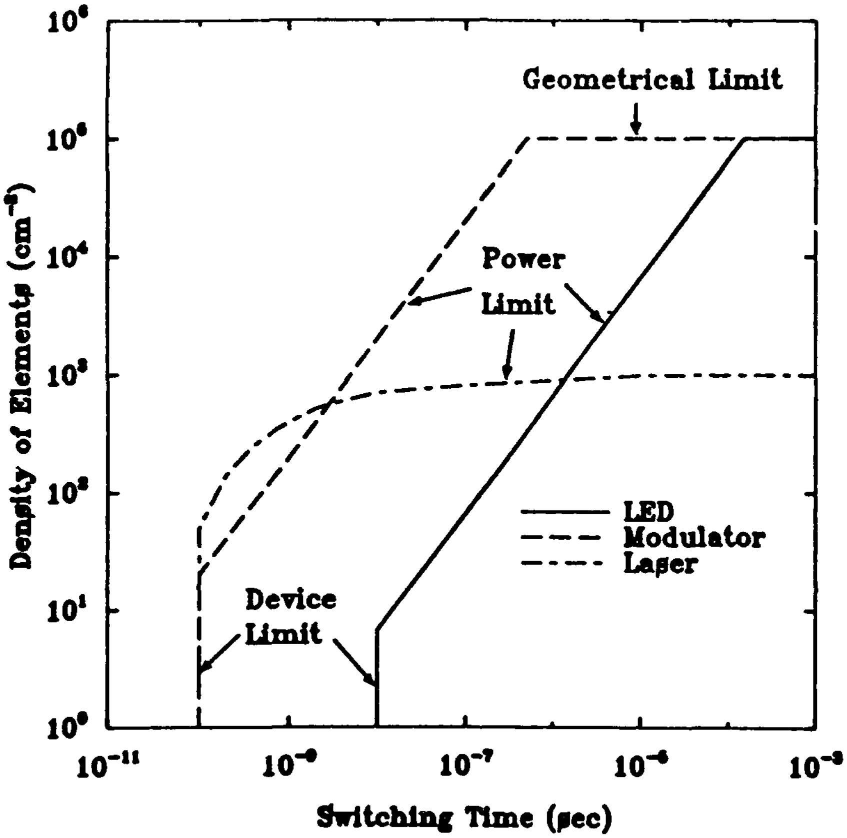

Figure 3. Density of Neurons as a function of the swithcing time of the circuit

The tradeoffs between bipolar and unipolar transistors are very significant. In bipolar transistors the current gain β is dependent on the collector current. Thus, for large current gains, one requires large collector currents, which means that the electrical power dissipation will be large. Since MESFETs are voltage controlled devices, this is not a problem. If the photocurrents in a MESFET circuit are small, it simply means that the switching time will be long due to the fixed charge needed on the gate of the MESFET to turn the LED on. MESFETs also have the advantage that the transconductance, or gain, can be varied with the geometry of the device.

We have fabricated a number of different circuits using different types of photodetectors and have discussed some of the tradeoffs in earlier reports. In terms of the figure of merit for neural network applications, we found that the MSM/MESFET/LED circuit had a figure of merit of 4×10^7 connection updates/sec-cm^2

while the optical FET/MESFET/LED circuit had a figure of merit of 1×10^9 connection updates/sec-cm^2. (Psaltis)

<u>**Publications and Presentations**</u>

Submitted

M. Mojahedie and M. Osinski, *Determination of operator ordering in effective-mass Hamiltonian from optical transition energies in GaAs/AlGaAs superlattices and quantum wells*, QELS '92 Conf. on Quantum Electronics & Laser Science, Anaheim, CA, May 10-15, 1992.

W. Nakwaski and M. Osinski, *Thermal analysis of top surface-emitting proton implanted microlasers*, QELS '92 Conf. on Quantum Electronics & Laser Science, Anaheim, CA, May 10-15, 1992.

W. Nakwaski, M. Osinski, M. Bugajski, and B. Mroziewicz, *Self-consistent semi-analytical approach to thermal and electrical characteristics of etched-well surface-emitting diode lasers*, IQEC'92 XVIII Int. Quantum Electronics Conf., Vienna, Austria, June 14-19, 1992

M. Mahbobzadeh and M. Osinski, *High-power-density pulsed operation of distributed-feedback vertical-cavity surface-emitting laser with resonant-periodic-gain active region*, QELS '92 Conf. on Quantum Electronics & Laser Science, Anaheim, CA, May 10-15, 1992.

M. Osinski, *Control of thermal problems in monolithically integrated vertical-cavity surface-emitting semiconductor laser arrays (invited paper)*, Second Int. Workshop on Photonic Networks, Components & Applications, Montebello, Quebec, Canada, March 9-11, 1992.

M. Osinski and W. Nakwaski, *Thermal crosstalk in two-dimensional arrays of etched-well surface-emitting diode lasers*, CLEO '92 Conf. on Lasers & Electro-Optics, Anaheim, CA, May 10-15, 1992.

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M. Mojahedie and M. Osinski, *Operator ordering in effective-mass Hamiltonian for semiconductor superlattices and quantum wells*, Techn. Digest, 3rd Annual Symp. on Ceramics & Advanced Materials, Albuquerque, NM, Oct. 24-25, 1991, pp. 18-19.

M. Mojahedie and M. Osinski, *Effects of operator ordering in effective-mass Hamiltonian on transition energies in semiconductor quantum wells*, Techn. Digest, OSA 1991 Annual Meeting, San Jose, CA, Nov. 3-8, 1991, Techn. Digest Series Vol. 17, Opt. Soc. of America 1991, Paper WH4, p. 113.

W. Nakwaski and M. Osinski, *Thermal properties of etched-well GaAs/AlGaAs surface-emitting diode lasers*, Techn. Digest, 3rd Annual Symp. on Ceramics & Advanced Materials, Albuquerque, NM, Oct. 24-25, 1991, pp. 16-17.

W. Nakwaski and M. Osinski, *Thermal analysis of etched-well surface-emitting diode lasers*, Microwave & Opt. Technology Lett. **4**, pp. 541-543 (Nov. 1991).

W. Nakwaski and M. Osinski, *Heat source distribution in etched-well surface-emitting semiconductor lasers*, IEEE Photonics Technology Lett. 3, pp. 979-981 (Nov. 1991).

W. Nakwaski and M. Osinski, *Optimization of thermal properties of etched-well surface-emitting GaAs/AlGaAs diode lasers*, Techn. Digest, OSA 1991 Annual Meeting, San Jose, CA, Nov. 3-8, 1991, Techn. Digest Series Vol. 17, Opt. Soc. of America 1991, Paper MHH4, p. 37.

M. Mahbobzadeh, E. Gandjbakhch, E. A. Armour, K. Zheng, S.-Z. Sun, C. F. Schaus, and M. Osinski, *Distributed-feedback vertical-cavity surface-emitting laser with resonant-periodic-gain active region*, Laser Diode Technology & Applications IV, SPIE Laser & Sensor Engineering Symp., OE/LASE'92, Los Angeles, CA, Jan. 19-24, 1992, Paper 1634-49. (accepted)

M. Mahbobzadeh, E. Gandjbakhch, E. A. Armour, K. Zheng, S.-Z. Sun, C. F. Schaus, and M. Osinski, *Distributed-feedback GaAs/AlGaAs/AlAs vertical-cavity surface-emitting laser with resonant-periodic gain active region*, Techn. Digest, 3rd Annual Symp. on Ceramics & Advanced Materials, Albuquerque, NM, Oct. 24-25, 1991, pp. 17-18.

M. Osinski and W. Nakwaski, *Thermal properties of etched-well surface-emitting diode lasers and two-dimensional arrays*, Laser Diode Technology & Applications IV, SPIE Laser & Sensor Engineering Symp., OE/LASE'92, Los Angeles, CA, Jan. 19-24, 1992, Paper 1634-08. (Accepted)

W. Nakwaski and M. Osinski, *Thermal analysis of two-dimensional etched-well surface-emitting diode laser arrays*, LEOS '91 Conf. Digest, IEEE LEOS 1991 Annual Meeting, San Jose, CA, Nov. 4-8, 1991, Paper SDL 3.5, p. 28.